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LENS ARRAY FOR USE IN PARALLEL OPTICS MODULES
FOR FIBER OPTICS COMMUNICATIONS

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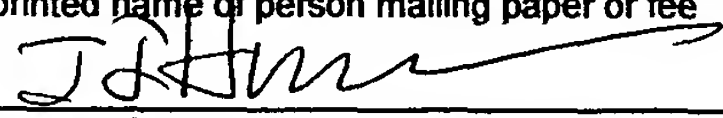
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LENS ARRAY FOR USE IN PARALLEL OPTICS MODULES FOR FIBER OPTICS COMMUNICATIONS

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FIELD OF THE INVENTION

The present invention relates generally to fiber optics communications and more specifically to parallel optics modules for use in fiber optic communications systems.

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BACKGROUND OF THE INVENTION

The majority of computer and communication networks today rely on copper wiring to transmit data between nodes in the network. However, copper wiring has relatively limited bandwidth for carrying electrical signals which greatly
15 constrains the amounts of data that it can be used to transmit.

Many computer and communication networks, including large parts of the Internet, are now being built using fiber optic cabling which has superior bandwidth capabilities and can be used to transmit much greater amounts of data. With fiber optic cabling, data is transmitted using optical or light signals
20 (sometimes also called photonic signals) rather than with electrical signals.

However, since computers use electrical signals as opposed to optical signals the light signals used to transmit data over fiber optic links must be translated to electrical signals and vice-versa during the optical communication process.

Building such fiber optic networks therefore requires optoelectronic modules
25 which mechanically and optically interface optical transmission mediums such as fiber optic cables to electronic computing and communications devices.

Further, in order to provide the required bandwidth for high-speed communications multiple fiber optic elements must be used in networking equipment often referred to as "parallel optics" systems for concurrently

30 transmitting multiple signals over a single cable. The associated optoelectronic

modules must therefore also be adapted for accommodating cables having multiple fibers which are presented for connection purposes in closely spaced arrays of fiber optic elements supported in special ferrules attached to the ends of the cables.

- 5 Signal conversion from electrical to optical and optical to electrical may be provided for through the use of corresponding arrays of semiconductor elements (photoactive components) which are deployed on semiconductor chips (optoelectronic devices). These photoactive components may typically be semiconductor devices such as photodiodes which act as photo-receivers or
- 10 laser diodes which act as photo-transmitters. While modules using such devices can provide satisfactory signal conversion performance, the building of effective parallel optics subassemblies is a challenge. The optical and mechanical alignment of the photoactive components with the ends of the thread-like fiber optic elements must be precise for effective transfer of optical
- 15 power. Since the fiber optic ends in parallel optics modules are closely spaced the complexity of this alignment task is further increased. Arrays of lenses are ordinarily positioned between the fiber ends and the photoactive devices for directing the photonic signals between them. The lens in these arrays need to be appropriately designed for efficiently collecting and focusing the light being
- 20 transferred between the fibers and semiconductor components and need to be precisely aligned and positioned between the fibers and semiconductor components for effectively directing the photonic signals.

SUMMARY OF THE INVENTION

The present invention relates to lens arrays for use in fiber optic
5 communications modules where multiple optical fibers are used for either
transmitting or receiving optical signals. The lens array is adapted for optically
interfacing a set of photoactive components such as semiconductor lasers or
photo diodes deployed on an optoelectronic device (integrated circuit chip) with
a set of optical communications fibers supported in an optical ferrule. The lens
10 array is linearly deployed and is characterized by a fixed pitch or center-of-lens
to center-of-lens distance which reflects the pitch of the fibers in the ferrule.
The individual lens elements within the array are sized to have a greater lens
diameter than the pitch distance and are accordingly laterally truncated at their
boundaries with adjoining lens halfway between the lens centers. The lenses
15 therefore have a greater height than lateral width. The increased height of the
lens elements allows them to gather and transfer more light than would be the
case with lenses having diameters which reflect the exact pitch of the fibers in
the fiber array. The lens array is deployed as an integral part of a one piece lens
and alignment frame. The lens and alignment frame includes a set of guide pins
20 which are accurately positioned with respect to the lens array. The guide pins
mate with corresponding alignment holes in the ferrule for precisely positioning
the lenses with respect to the fibers in the ferrule. The fibers and lenses are in
turn also precisely aligned with the photoactive components of the
optoelectronic device (integrated circuit chip) which is attached to a carrier
25 assembly onto which the lens and alignment frame is precisely mounted.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention and its advantages may best be understood by reference to the
5 following description taken in conjunction with the accompanying drawings in
which:

FIGURE 1 is an overhead, perspective view of a fiber optic communications
module constructed in accordance with the principles of the present invention
10 showing a ferrule supporting multiple optical communications fibers
interconnected with an optoelectronic subassembly for use in converting optical
signals to electrical signals or vice-versa.

FIGURE 2 is an overhead, perspective view of the fiber optics communications
assembly shown in FIGURE 1 with the ferrule disconnected from the
15 subassembly and the subassembly unplugged from the jack to or from which it
transfers electrical signals.

FIGURE 3 is a front end view of the ferrule shown in FIGURES 1-2, showing,
among other things, the optical fiber element ends and alignment holes.

FIGURE 4 is a front end view of the optoelectronic subassembly shown in
20 FIGURES 1-2 showing, among other things, the lens and alignment frame
including the lens array and the guide pins.

FIGURE 5 is a side view of the fiber optic communications module shown in
FIGURE 1 illustrating, among other things, the position of the carrier assembly
within the subassembly and how the optoelectronic subassembly may be
25 pluggably connected to a jack mounted on printed circuit board of a
communications system or the like.

FIGURES 6 is an exploded, overhead perspective view of the subassembly of
the present invention showing, among other things, how the casing structure,
receptacle, lens and interface frame, carrier frame section, circuit board, edge

connector and the other components of the optoelectronic subassembly relate to one another.

FIGURE 7 is an enlarged exploded, overhead perspective view of the front portion of the subassembly of the present invention showing, among other things, how the casing structure, receptacle, lens and interface frame, and carrier frame section relate to one another.

FIGURE 8 is a perspective view of the one-piece lens and alignment frame component of the present invention showing, among other things, the tower structure and the lens array and guide pins which are built into the tower structure.

FIGURE 9 is a vertical cross sectional view of the lens and alignment frame of the present invention taken along lines 9-9 of FIGURE 8 showing again, among other things, the arrangement of the tower structure, lens array and guide pins.

FIGURE 10 is a vertical sectional view of the carrier frame section, lens and alignment frame, receptacle (inner end) and ferrule (proximal end) in assembled form showing, among other things, the vertical alignment of the ferrule with the lens and alignment frame and the carrier frame section and the alignment of the lens array with the optoelectronic device.

FIGURE 11 is a lateral sectional view of the carrier frame section, lens and alignment frame, receptacle (inner end) and ferrule (proximal end) in assembled form showing, among other things, the lateral alignment of the ferrule with the lens and alignment frame and the carrier frame section and the alignment of the optical fibers with the lens array and the optoelectronic device.

FIGURE 12 is an enlarged vertical sectional view around lines 12-12 of FIGURE 10 illustrating the upper portions of the carrier frame section and lens and alignment frame in assembled form showing, among other things, the lens elements making up the lenses in the lens array and the alignment of the tower of the lens and alignment frame with the window in the back wall of the

receptacle and the alignment of the lens elements with the optoelectronic device.

FIGURES 13 is a plan view of the lens array and lens elements comprising the lenses of the lens array which is part of the lens and alignment frame showing
5 the vertically elongated shaping of these lens elements and their deployment with respect to each other.

TOP SECRET

DETAILED DESCRIPTION OF THE INVENTION

The present invention will now be described in detail with reference to
5 preferred embodiments as illustrated in the accompanying drawings. In the
following description, numerous specific details are set forth in order to provide
a thorough understanding of the present invention. However, it should be
apparent to one skilled in the art that the present invention may be practiced
without some or all of these specific details. In other instances it should be
10 appreciated that well-known process steps have not been described in detail in
order to not obscure the present invention.

Referring now to FIGURES 1 and 2, a fiber optic connector assembly 10 is
shown as comprising an optical ferrule 12 of the type sometimes referred to in
the industry as an MT ferrule installed on the end of a cable 14 carrying
15 multiple fiber optic communication elements 17 (not shown in FIGURES 1-2)
and an optoelectronic subassembly 16 which operates as a transceiver module
for either transmitting light (photonic) signals or receiving light signals and
converting these signals to or from electrical signals. The subassembly 16
includes a small printed circuit board (PCB) 18 having an edge connector 20
20 with connection pads 25 on both sides which can be readily plugged into and
out of an electrical connection jack 22 (in phantom) mounted on a circuit board
24 (in phantom) of a computer or communications system to or from which
data can then be relayed over the cable 14 through the subassembly 16. The
ferrule 12 and subassembly 16 are adapted for interconnection when the
25 proximal end 26 of the ferrule 12 is inserted and latched within a cavity 28 in
the subassembly 16. The ferrule 12 and subassembly 16 are then positioned
and aligned so that optical signals can be transmitted either to or from the
ferrule 12 and from or to the subassembly 16 for enabling data flow between
the cable 16 and printed circuit board 24 (in phantom).

30 Referring now to FIGURE 3, the proximal end 26 of the ferrule 12 is shown

which includes a pair of alignment holes 30 and a set of twelve optical communications fibers 17 having polished fiber ends 32. The fibers 17 and their polished ends 32 are rigidly supported within the ferrule 12. The fiber ends 32 are disposed in a linear array 33 at regular 250 micron intervals along a line extending between the alignment holes 30. The fiber ends 32 are precisely aligned with the holes 30.

Referring now to FIGURE 4, the cavity 28 is defined by a receptacle 35 having jaws 42 for latching onto the ferrule 12. A pair of alignment or guide pins 34 and a set of twelve lenses 46 are disposed in a linear array 48 at regular 250 micron intervals along a line extending between the guide pins 34. The lenses 46 and guide pins 34 are part of a lens and alignment frame 44 which is deployed at the inner end of the cavity 28. As will be later described a set of twelve photoactive components 36 (not shown) are disposed behind the lenses 46 as part of an integrated circuit (IC) chip that comprises an optoelectronic device 40 (not shown in Fig. 4). When the proximal end 26 of the ferrule 12 is latched into the cavity 28 by the jaws 42 the guide pins 34 in the subassembly 16 are engaged with the alignment holes 30 in the ferrule 12 which in turn precisely aligns the lenses 46 in the array 48 (and photoactive components 36 behind the lenses) with the fiber ends 32 in the array 33 so that photonic signals can pass between them.

Referring now to FIGURE 5, the parallel optics assembly 10 is shown with the ferrule 12 latched into the subassembly 16 and with the edge connector 20 (in phantom) plugged into the jack 22 so that the pads 25 are in electrical contact with the elements of a connector lead frame (not shown) within the jack 22. The jack 22 is surface mounted on the circuit board 24 and thereby electrically interconnected with the circuitry on the board 24 and the computer or communication system of which the board is a part. The edge connector 20 and jack 22 enable the subassembly 16 to be removably connected to the board 24. The subassembly 16 includes a carrier assembly 50 (mostly in phantom) which

has a planar carrier frame section 52 at one end which is sandwiched in between the ferrule 12 and a heat sink 54 along with the lens and alignment frame 44. The lens and alignment frame 44 is positioned between the carrier frame section 52 and the ferrule 12 and acts as an interface between them and the components supported in or mounted on them. The carrier assembly 50 also includes a flex circuit 60 (in phantom) which is bendable and which also serves as an integral part of both the frame section 52 and the circuit board 18. The flex circuit 60 extends under the heat sink 54 from the carrier frame section 52 at its one end to the circuit board 18 at its opposite end.

Referring now to FIGURES 6 and 7, the subassembly 10 includes the receptacle 35, metal casing structure 45, lens and alignment frame 44, carrier assembly 50, heat sink 54 and casing structure 47. As previously explained the receptacle 35 is adapted for receiving the ferrule 12 in the cavity 28. The receptacle is mounted in the recess 29 in the casing structure 45 so that it abuts the back wall 51 of the recess 29. The carrier assembly 50 includes the printed circuit board 18, the flex circuit 60 and the carrier frame section 52. The lens and alignment frame 44 is mounted in between the frame section 52 of the carrier assembly 50 and the back wall 51 of the casing structure 45 so that it is immediately adjacent to the fiber ends 32 on the proximal end 26 of the ferrule 12 when the ferrule is latched into the subassembly 16. The flex circuit 60 connects the frame section 52 to the circuit board 18 serving as a medium for providing a large number of connection lines between components on the carrier frame section 52 and the circuit board 18 including the microcontroller chip 23 and the edge connector 20. The circuit board 18 fits along the back shelf 53 of the casing structure 45 underneath the heat sink 54. The front end 59 of the heat sink 54 abuts the backside of the carrier frame section 52 for dissipating heat generated during operation by the electrical components mounted onto the frame section 52. Except for the heat sink the metal cover 47 fits around the subassembly 16 providing a covering and protection for the

receptacle 35, casing structure 45 and the components of the carrier assembly 50 including the circuit board 18 extending along the back shelf 53 of the casing structure 45. The bolts 58 help retain the heat sink 54 and circuit board 18 in position. As shown more clearly in FIGURE 7, the casing structure 45 includes a window 37 in its back wall 51. The lens and alignment frame 44 includes a mostly planar base 56 and a rectangular tower structure 43 projecting forward of the base 56 on which the guide pins 34 and lens array 48 are mounted. The tower 43 of the lens and alignment frame 44 fits through the window 37 of the casing structure 45 in the assembled device. The lens and alignment frame 44 is one-piece precision plastic injection-molded part including the tower 53, guide pins 34 and lens array 48. The frame section 52 of the carrier assembly 50 preferably includes one or more layers of printed circuit board material including a layer of flex circuit material 61 which is an extended part of the flex circuit 60. The optoelectronic device 40 is precisely mounted on the frame section 52 and includes the photoactive semiconductor components 36 which are deployed on and as part of an integrated circuit (IC) chip that comprises an optoelectronic device 40. The photoactive components 36 may be either semiconductor transmitter elements or semiconductor receiver elements and are disposed in a linear array 38 at regular 250micron intervals corresponding to the linear array 48 of lenses and the linear array 33 of fibers. When the lens and alignment frame 44 is mounted on the frame section 52 the optoelectronic device 40 and photoactive components 36 are precisely aligned with the lens array 48 and the guide pins 34. If the photoactive elements 36 are intended to be transmitter elements (a transmitter subassembly) they may, for example, be light emitting diodes (LEDs) or laser diodes. They are preferably vertical cavity surface-emitting lasers (VCSELs). If the photoactive elements 36 are intended to be receivers elements (a receiver subassembly) they may, for example, be PIN photodiodes or avalanche photodiodes (APDs) although they are preferably PIN photodiodes. One or more signal processing chips 41 may be

mounted on the frame section 52 for communicating with the optoelectronic device 40 and more particularly providing drive signals to transmitter elements or providing signal amplification and conditioning in the case of receiver elements.

5 Referring now to Figures 8 and 9, the lens and alignment frame 44 includes a main body or base 56 and a tower 43. The base 56 is mostly planar and includes cavities 57 into which adhesive materials can flow during mounting and a large but shallow recess 55 for accommodating components and wiring on the front side of the carrier frame section 52 on which the lens and alignment frame 44 is
10 mounted. The tower 43 resides on the front side of the frame section 52 and projects well forward of the base 56. The tower 43 includes a pair of turret-like elevated end sections 49 on top of which the guide pins 34 are mounted so as to project outward and forward from the base 56 and lens array 48. The lenses 46 in the array 48 are deployed at regular 250 micron intervals along a line
15 extending between the elevated end sections 49 and guide pins 34 in a manner corresponding to the arrangement of the photoactive components 36 of the optoelectronic device 40 and fibers 17 of the ferrule 12. The lenses 36 are precisely aligned with the guide pins 34. Each lens 46 in the array 48 includes a front lens element 46a and a rear lens element 46b for directing light to and
20 from the fiber ends 32 and photoactive components 36, respectively.

Referring now to FIGURES 10 and 14, the lens and alignment frame 44 is precisely mounted on the carrier frame section 52 and cooperates with the receptacle 35 in achieving alignment with the ferrule 12. The frame section 44 is mounted flush on the front side of the frame section 52 using epoxy adhesive
25 so as to carefully center the lens array 48 over the optoelectronic device 40 and more particularly the array 38 of photoactive components 36 which comprises the optoelectronic device 40. The recess 55 in the frame 44 provides space to accommodate the chips 40 and 41 and to accommodate the wire bonds whereby the chips 40 and 41 are interconnected and connected to the signal traces on the

flex circuit 60 part of the carrier assembly 50. The frame section 52 preferably includes a flex circuit layer 61, a layer of FR-4 printed circuit board material and a thin layer 63 of copper plate. The signal processing chip 41 may then be mounted in a small well 65 in the flex circuit layer 61 and circuit board layer 62 of the frame section 52 so that it is in direct contact with the copper layer 63 to improve heat dissipation in connection with the operation of the heat sink 54 which is attached to the layer 63 on the backside of the frame section 52. The tower 43 passes through the window 37 in the casing structure 47 and fits into a second window 31 in the back wall at the inner end of the receptacle 35 which assists in making sure that the receptacle is aligned with the frame 44 and the frame section 52 and ferrule 12 are then aligned as the ferrule 12 is latched into the receptacle 35. The guide pin 34 of the lens and alignment frame 44 fits into the alignment hole 30 in the ferrule 12 for precisely aligning the array 33 of optical fibers 17 (not shown in FIGURE 10) with the lens array 48.

Referring now to FIGURE 11, it can be seen again that the lens and alignment frame 44 is mounted on carrier frame section 52 so that the array 48 of lenses 46 is aligned with the optoelectronic device 40 and accordingly with the linear array 38 of photoactive components 36 which comprise the optoelectronic device 40. The ferrule 12 is in turn coupled to the lens and alignment frame 52 by the action of the guide pins 34 which closely fit into the alignment holes 30 when the ferrule is inserted and latched into the receptacle 35 of the subassembly 16. Since the lens array 48 and fiber array 33 are accurately positioned with respect to the guide pins 34 and alignment holes 30, the guide pins and alignment holes 30 are operative for aligning the array 33 of optical fibers 17 with the array 48 of lenses 46. The lens and interface frame 44 thereby provides for the alignment of the array 33 of fibers 17 with the array 48 of lenses 46 and with the optoelectronic device 40 and more particularly with the array 38 (not shown) of photoactive components 36 (not shown) in the optoelectronic device 40. The alignment of the fibers 17 with the lenses 46 and

the photoactive components of the optoelectronic device 40 (semiconductor chip) enables the transmission of photonic (light) signals from the optoelectronic device 40 to the fibers 17 in a transmitter subassembly 16 or from the fibers 17 to the optoelectronic device 40 in a receiver subassembly 16.

5 The lens and alignment platform 44 also serves to fix the distances over which light is focused by the lenses 46. These distances are established by the offsets from the lenses 46 in the frame 44 to the frame section 52 and optoelectronic device 40 one side (across the recess 55) and to the ferrule 12 and fibers 17 on the other side.

10 Referring now to FIGURE 12, the lenses 46 are biconvex in shape and are each comprised of two planoconvex lens elements 46a and 46b on the front and back sides of the central section of the tower 43 of the lens and alignment frame 44 between the elevated end sections 49. Also, referring again to FIGURE 11, the individual lenses 46 are operative for directing light to and from the individual
15 fibers 17, through the lens and alignment frame 44 and to and from the individual photoactive components in the optoelectronic device 40. The lens elements 46a are adapted for focusing light to and from the fibers 17 while the lenses elements 46b are adapted for focusing light to and from the optoelectronic device 40. In the preferred embodiment the lens elements 46a and 46b making up the lenses 46 may, by way of example, be characterized by
20 the values shown in TABLE I.

TABLE I

<u>Lens Element Key Parameter Values</u>			<u>Lens Element Sag Values</u>		
	LENS 1 (46b)	LENS 2 (46a)		LENS 1	LENS 2
N (index) (um)	1.632	1.632	r (um)	z (um)	z (um)
D (focus) (um)	300	450	50	6.412449	4.340131
k	-2.663424	-2.663424	100	23.87155	16.75945
R (radius at apex)	189.6	284.4	150	48.86220	35.80733
half aperture (um)	200	200	200	78.47245	59.84856
z (sag) (um)	78.47245944	59.84856468			
LENS 1	element 46b	Device side			
LENS 2	element 46a	Fiber side			

The lens elements 46a (fiber side) have a focal length D of about 450 microns and the lens elements 46b (device side) have a focal length D of about 300 microns with the fibers 17 and optoelectronic device 40 then being positioned at or near the focal points of these lens elements. However, the fibers 17 may
5 be preferably positioned away from the focal points by about 100-200 microns toward the lens element 46a. This may allow the some of the light emitted in transmitter subassemblies at higher off-axis angles by transmitter components 36 such as VCSELs which is subject to slower modulation patterns to be focused (or rather defocused) away from the fiber ends 32 of the fibers 17. The
10 optimal amount of defocusing depends on the numerical aperture values of the VCSELs and the fibers.

Referring now to FIGURE 13, the lenses 46 are collinearly and contiguously positioned in the lateral direction from end to end across the array 48. The lenses 46 are characterized by a vertically elongated shape and have a greater
15 height than width. The lenses 75 on the interior of the array 48 are about 400 microns high in the vertical direction 70 and are about 250 microns wide in the lateral direction 72. The lenses 46 intersect along extended common boundaries 76 extending out from the centerline of the array 48 by about 156 microns with each boundary measuring about 312 microns in total length. The lenses 46 are
20 in effect truncated in the lateral direction at their boundaries 76. In effect the lenses 46 are extended vertically and are larger than the natural 250 micron pitch (center-of-lens to center-of-lens distance) of the array 48. The elongated lenses 46 provide improved light gathering characteristics and improved tolerance to mechanical misalignments affecting optical coupling efficiency as
25 compared to smaller symmetrically shaped lens designed to intersect at a point along the centerline of the array 48.

Although only a few embodiments of the present invention have been described in detail, it should be understood that the invention may be embodied in other forms without departing from its overall spirit or scope.